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The Swiss iodized salt program provides adequate iodine for school children and pregnant women, but weaning infants not receiving iodine-containing complementary foods as well as their mothers are iodine deficient

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Abstract: **BACKGROUND:** If children and pregnant women in the population are iodine sufficient, it is generally assumed infants are also sufficient. But weaning infants may be at risk of iodine deficiency because iodized salt contributes little dietary iodine during this period. To fill this gap, iodine fortification of infant formula milk (IFM) and complementary foods (CF) is likely important. **OBJECTIVES:** The objective of the study was to first confirm that Swiss school children and pregnant women remain iodine sufficient and then to assess iodine status in infancy and the relative contribution of breast milk and IFM/CF to their iodine intakes. **METHODS:** We measured urinary iodine concentrations (UIC) in national cross-sectional samples of: 1) pregnant women (n=648); 2) school children (n=916); 3) infants at three time points: at 3-4 d after birth and at 6 and 12 months (n=875); and 4) breast-feeding mothers (n=507). We measured breast milk iodine concentrations in the mothers, assessed iodine sources in infant diets, and analyzed iodine content of commercial IFM/CFs (n=22) and salt samples from the school children's households (n=266). **RESULTS:** Median (m) UICs in pregnant women (162 g/liter) and school children (120 g/liter) were sufficient, and 80% of the household salt was adequately iodized (15 ppm). However, mUICs in infants not receiving IFM/CF were not sufficient: 1) mUIC in breast-fed infants (82 g/liter) was lower than in non-breast-fed infants (105 g/liter) ($P < 0.001$) and 2) mUIC in breast-fed weaning infants not receiving IFM/CF (70 g/liter) was lower than infants receiving IFM (109 g/liter) ($P < 0.01$). mUIC was low in lactating mothers (67 g/liter) and median breast milk iodine concentration was 49 g/kg. **CONCLUSIONS:** In countries in which iodized salt programs supply sufficient iodine to older children and pregnant women, weaning infants, particularly those not receiving iodine-containing IFM, may be at risk of inadequate iodine intakes.

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The Swiss iodized salt program provides adequate iodine for school children and pregnant women but weaning infants not receiving iodine-containing complementary foods as well as their mothers are iodine deficient

Abbreviated title: Iodine deficiency in infancy

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Key words: iodine, deficiency, infant, pregnancy, children, infant formula, complementary foods

Precis: Weaning infants are not covered by salt iodization and may be at risk of iodine deficiency. Thus, iodine fortification of infant food may be important in otherwise iodine sufficient populations.

Abstract

Background If children and pregnant women in the population are iodine sufficient, it is generally assumed infants are also sufficient. Weaning infants may be at risk of iodine deficiency, because iodized salt contributes little dietary iodine during this period. To fill this gap, iodine in infant formula milk (IFM) and complementary foods (CF) is likely important.

Objectives First, to confirm that Swiss school children and pregnant women remain iodine sufficient; then, to assess iodine status in infancy and the relative contribution of breast milk and IFM/CF to their iodine intakes.

Methods We measured urinary iodine concentrations (UIC) in national cross-sectional samples of: 1) pregnant women (n=648); 2) school children (n=916); 3) infants at 3 time points: at 3-4 d after birth, and at 6 and 12 mo (n=875); and 4) breastfeeding mothers (n=507). We measured breast milk iodine concentrations (BMIC) in the mothers, assessed iodine sources in infant diets and analyzed iodine content of commercial IFM/CFs (n=22) and salt samples from the school children's households (n=266).

Results Median (m) UICs in pregnant women (162 µg/L) and school children (120 µg/L) were sufficient and 80% of the household salt was adequately iodized (≥ 15 ppm). However, mUICs in infants not receiving IFM/CF were not sufficient: a) mUIC in breast-fed infants (82 µg/L) was lower than in non-breast fed infants (105 µg/L) ($p < 0.001$); b) mUIC in breast-fed weaning infants not receiving IFM/CF (70 µg/L) was lower than infants receiving IFM (109 µg/L) ($p < 0.01$). mUIC was low in lactating mothers (67 µg/L) and mBMIC was 50 µg/kg.

Conclusions In countries where iodized salt programs supply sufficient iodine to older children and pregnant women, weaning infants, particularly those not receiving iodine-containing IFM, may be at risk of inadequate iodine intakes.

1 Introduction

2
3 Because iodine deficiency (ID) during infancy may irreversibly impair development and
4 increase mortality (1, 2), control of ID in populations should emphasize this critical period.
5 Infants are at high risk for ID because their requirements per kg body weight for iodine and
6 thyroid hormone are much higher than at any other time in the life cycle. In areas of iodine
7 sufficiency, thyroidal iodine content is only $\approx 300 \mu\text{g}$ at birth (3) and T_4 turnover is high, with
8 estimated production rates of $5\text{--}6 \mu\text{g/kg}$ body weight/day in infancy (4).

9
10 Infants may be at particularly high risk for ID during the weaning period. Iodization of salt is
11 the recommended strategy to control ID, and lactating mothers consuming iodized salt can
12 transfer the iodine to the infant via breast milk. But experts recommend no extra salt
13 (iodized or not) be given to infants during the first year and mothers are encouraged to feed
14 home-prepared complementary formula/foods (CF) without added salt after 6 mo (5, 6). So
15 as infants wean from breast milk, iodized salt programs contribute little to their iodine
16 intakes, and, in industrialized countries, they depend nearly entirely on iodized commercial
17 CF. However, European legislation does not stipulate minimum iodine levels for CF (7), and a
18 U.S. study found iodine content of these foods is unpredictable (8).

19
20 There have been no national studies assessing infant iodine status in countries with
21 established iodized salt programs where the general population has adequate iodine intakes.
22 Previous infant studies were limited by small non-representative sampling and, in many, the
23 iodine intake of the population was too high, or was inadequate (9). The main indicator of
24 iodine intake in populations is the median (m) urinary iodine concentration (UIC) and WHO

states a mUIC ≥ 100 $\mu\text{g/L}$ in infants indicates iodine sufficiency (10). A challenge to assessing UIC in this age group is sample collection, but we have recently developed and validated a simple pad collection method (11).

Switzerland has a model iodized salt program that was initiated in 1922; in national surveys in 1999 and 2004, >90% of households were using iodized salt and school children were iodine sufficient (12, 13). However, according to national Swiss salt legislation, iodization of salt is not compulsory and all retail outlets must offer both iodized (at a level of 20 ppm) and non-iodized salt (13). The first objective of the present study was to measure UIC in a national sample of pregnant women and school children to confirm that the Swiss population remains iodine sufficient in 2009. At the same time, we measured UIC in a national sample of infants during the 1st week, and at 6 mo and 12 mo of age. We also measured breast milk iodine concentrations (BMIC) in the mothers of the infants, and assessed the relative contribution of BMIC, infant formula milk (IFM) and CF to iodine intakes during this vulnerable period.

Subjects and methods

Subjects were recruited using a stratified probability-proportionate-to-size (PPS) cluster design. Based on current census data, the Swiss Federal Office of Statistics divided Switzerland into five geographic regions and divided each of these regions into three strata with communities with different population size. Then, a two-stage PPS random cluster sampling (10) was used to obtain independent national samples of the population groups. Following WHO recommendations for cluster sampling in iodine surveys (10), for the

pregnant women and school children, we aimed for 30 clusters including ≈ 20 subjects, and for the newborns and the infant/mother pairs, we aimed for 20 clusters including ≈ 20 subjects. For infants, PPS sampling was based on the birthrate of the seven greater Swiss regions. The collection periods were November 2005 to September 2007 (11) and August 2008 to November 2009. The ethical committee at the ETH Zürich approved the study and written informed consent was obtained from all participants and/or their parents; oral assent was obtained from the school children.

Newborns and infant/mother pairs

For the newborns, within each sampling cluster, a maternity clinic was randomly selected and newborns were sequentially enrolled at each clinic. Inclusion criteria were: 1) full-term, healthy pregnancy; 2) parental residence in Switzerland for ≥ 12 months; 3) no history of thyroid disorders; 4) no ingestion of iodine-containing drugs or contrast media during gestation; 5) delivery without use of iodine-containing disinfectants; 6) age, 3 or 4 days after birth; and 7) exclusive breastfeeding. The centers collected spot urine samples using a pad collection method (11). Mothers filled out a registration form including birth data, infant feeding, and history of maternal use of iodized salt and/or iodine-containing supplements during pregnancy.

For the infant/mother pairs, within each sampling cluster, an outpatient pediatric clinic was randomly selected and ≈ 25 pairs were sequentially enrolled at each clinic. The French-speaking part of Switzerland was not represented. Mother-infant-pairs were enrolled at the clinics according to the inclusion criteria above for the newborns, but additionally: a) infant age of 6 mo ± 6 wk or 12 mo ± 6 wk; b) no health problems in the infant; c) residence in

Switzerland since delivery. Spot urine samples were collected from the infant and the mother. A 10 ml breast milk sample was collected by manual expression. Weights and heights of the infants were measured. The mothers filled in a dietary questionnaire including current infant feeding practices and use of iodized salt in the home; the questionnaire also included information on height, weight, number of children, nutritional supplement use, cigarette smoking, professional activity and education/profession of the mother.

Pregnant women

The proportion of Swiss pregnant women who receive prenatal care in private practices vs. hospitals is 4-5:1; this proportion was used in the selection of the prenatal clinics within the sampling clusters (personal communication, Swiss Society for Obstetric and Gynecology, May 2009). Inclusion criteria were: a) residence in Switzerland since the beginning of the pregnancy; b) no treatment for thyroid disease during the pregnancy; c) no exposure to iodinated contrast medium or amiodarone in the previous 12 months. The participants completed a questionnaire on use of iodized salt and/or nutritional supplements. A spot urine sample was collected.

School children

Within each sampling cluster, 2 to 3 classes in a primary school were randomly selected and all children in the classes who consented were enrolled. Height and weight were measured using standard anthropometric techniques (14). A spot urine sample was collected. At all schools except one, urine samples were collected before noon. In each school, 10 children were randomly selected and given plastic bags for collection of a household salt sample..

Content of iodine in commercial infant foods

The iodine concentration of commercial infant foods was directly analyzed and compared with the labeled concentration. These were: 1) IFM products (infant formulas 2x, follow-on formulas 9x, soy-based formula 1x; all instant powders); and 2) commonly-consumed baby cereal products (4 instant powder) (**Table 1**). Selection of products was based on the brands most frequently used by the participating families as indicated in the dietary questionnaires, and the samples were purchased from retail outlets in the Zurich area. All infant foods were analyzed in dry form (0.25 g powder) and wet form, that is, a ready-to-eat portion was prepared in Nanopure water and 1.5-2.0 g of the food was sampled for the analyses..

Laboratory analysis

All urine, breast milk and salt samples were frozen and kept at -25°C until analysis. UIC and salt iodine content were measured in duplicate at the ETH Zürich by using a modification of the Sandell-Kolthoff reaction with spectrophotometric detection (15). By this method, the CV for UIC (\pm SD) in our laboratory is 11.5% at 31 ± 4 μ g/L and 3.6% at 212 ± 8 μ g/L. External control was provided by inductively coupled plasma mass spectrometry (ICP-MS) (Finnigan ELEMENT 2, Thermo Scientific, USA) measurements of 10% of UIC samples (SAC, PW) at the Swiss Federal Office of Public Health (Liebefeld, Switzerland). The agreement between the Sandel-Kolthoff and ICP-MS methods was high ($r=0.97$, $P<0.001$). The ETH iodine laboratory participates successfully in EQUIP (Program to Ensure the Quality of Urinary Iodine Procedures) (16). Breast milk iodine and iodine content of infant foods were measured by ICP-MS using isotope dilution analysis (17). Alkaline extraction with diluted tetra methyl ammonium hydroxide was used to prepare the sample, the sample was spiked with I^{129} and the ratio of the natural abundant stable isotope I^{127} to the radioactive isotope

I¹²⁹ was directly measured. The infant food analyses were verified with an external control (Standard 1846, National Institute of Standards and Technology, Gaithersburg, MD, USA).

Statistical analysis

EXCEL (XP 2003; Microsoft; Seattle; WA), SPSS 16.0 and PASW 18.0 (SPSS, Inc.; Evanston; IL) were used for data processing and statistics. Normally distributed data were expressed as means \pm SDs; non-normally distributed data (UIC) were expressed as medians (ranges, and/or 95% CI obtained by 1000 bootstrap samples). Group differences for continuous variables were tested by using Wilcoxon or Mann Whitney U tests with Bonferroni correction when indicated. To look for correlations, Spearman or Pearson correlations were done. A multiple linear regression analysis was done with log infant UIC as the dependent variable and including sex, current breast milk- and IFM consumption, log BMIC and log UIC of mothers as covariates. P values <0.05 were considered significant.

Results

Newborns

Twenty four participating clinics provided samples from exclusively breastfed infants on days 3 or 4 after birth that matched the inclusion criteria (n=368: day 3, n=248, day 4, n=120). Ninety percent were delivered vaginally, and all were term infants, with normal birth weights and Apgar scores. Median UIC was 91 μ g/L (**Table 2**); at day 3, mUIC was 87 μ g/L and at day 4, it was 100 μ g/L. Among the mothers, 65% (n=241) were taking supplements, but only 0.8% (n=3) were consuming iodine-containing supplements (during pregnancy or currently), and 12% (n=42) were using non-iodized salt.

1 *Infants and their mothers*

2 Eighteen participating clinics provided 507 infant/mother pairs. The ratio of
3 vaginal/caesarean deliveries was 208/70 and 174/54 in the 6 and 12 mo olds, respectively.
4 The UICs in the 6-mo and 12 mo infants is shown in Table 2 and were not significantly
5 different. The overall infant mUIC was 98 µg/L (95% CI: 89, 105). The UICs did not differ
6 significantly among geographic regions or pediatric clinics, but girls had higher UICs than
7 boys (mUIC, 103 vs. 88 µg/L) ($p<0.05$). The mean (\pm SD) parity of the mothers was 1.7 ± 0.8 .
8 Their mUIC was 75 µg/L (95% CI 69, 81) (Table 2) and their mBMIC was 48.9 µg/kg ($n=179$).
9 The mUIC of lactating women did not significantly differ from non-lactating women (67 µg/L,
10 $n=196$ vs. 81 µg/L, $n=311$). The mBMIC of mothers in the 6-mo group (50.6 µg/kg, $n=149$) did
11 not significantly differ from the BMIC of the 12-mo group (42.3 µg/kg, $n=32$). The BMIC of
12 the mothers was positively correlated with the UIC of their infants ($r^2=0.32$, $p<0.001$).

13
14 Fifty seven percent of the 6 mo old infants and 18% of the 12 mo old infants were being
15 breast-fed fully or partly at the time of sampling. Breast-fed infants with or without IFM had
16 a lower mUIC than infants not currently breast-fed (82 µg/L, $n=196$ vs. 105 µg/L, $n=311$)
17 ($p<0.001$). About 60% of all infants were receiving IFM and their mUIC was higher than those
18 not receiving IFM (109 µg/L, $n=304$ vs. 73 µg/L, $n=203$) ($p<0.001$). Infants (breast-fed and/or
19 CF) receiving IFM had higher mUIC than breast-fed weaning infants who did not receive IFM
20 (109 µg/L, $n=304$ vs. 70 µg/L, $n=131$) ($p<0.01$) (**Figure 1**). Weaned infants not receiving
21 breast milk or IFM did not differ in UIC (89 µg/L, $n=72$) from the other two groups. Eighty
22 four percent of mothers were using iodized salt at home, 8% of mothers were not using
23 iodized salt and 8% were unsure; there were no significant differences in UIC of the mothers
24 or infants among these 3 groups. Among the 6 mo infants, nearly 4 out of 5 were already

receiving complementary foods, and at 6 and 12 mo, 7 and 95% of infants were receiving some foods from the family table. The mUIC of infants receiving some iodized salt in complementary foods (103 µg/L, n=287) was higher, but not significantly different from the mUIC of infants not receiving iodized salt (89 µg/L, n=189).

Thirty two percent of the mothers were taking nutritional supplements (n=158), but only 3% of women were consuming iodine-containing supplements. There were no significant monthly differences in the UICs of infants or mothers, or the BMICs, suggesting no major seasonal fluctuations in iodine supply to these groups. Ten percent of the mothers were current smokers, but the UIC of the smoking mothers and their infants was not significantly different than those not smoking. Predictors of infant UIC are shown in **Table 3**.

Iodine content of infant foods

The agreement between the labeled and analyzed iodine content of the IFMs and infant cereals was high (Table 1); the mean (\pm SD) difference [%] between labeled and measured values was $13.5 \pm 9.1\%$ for the formulas and $4.5 \pm 2.6\%$ for the cereals. None of the formula milks or cereals exceeded the recommended maxima of 50 µg and 35 µg /100 kcal (18). The agreement between the iodine content of the wet vs. dry form of the infant foods was high (data not shown for the dry form).

Pregnancy

A total sample of 648 women from 27 practices (6 hospitals and 21 private practices) participated in the pregnancy study. The mUIC was 162 µg/L (95% CI: 144, 177) and 47% of pregnant women had a UIC <150 µg/L (Table 2). The percentage of pregnant women who

1 reported using iodized salt was 74% (n=480). The mUIC of the subjects using iodized salt was
2 162 µg/L, while mUIC of the women not using iodized salt was 173 µg/L (N.S.). The mUIC of
3 the 17% (n=108) reported not knowing what type of salt they were using was 187 µg/L and
4 the mUIC in the subjects (9%) (n=60) who reported using noniodized salt was 176 µg/L. The
5 UIC did not significantly differ among the 3 groups.

6
7 Seventy-nine percent of the pregnant women were taking nutritional supplements, but only
8 15% (n=100) were taking supplements containing iodine. The amount of iodine in the iodine-
9 containing supplements ranged from 45 µg to 200 µg/dose, mainly as potassium iodide (KI).
10 The mUIC in the women taking/not taking iodized supplements was 198 µg/L vs. 155 µg/L
11 (N.S.). The mUIC of women in the 1st trimester of pregnancy (n=20) was 116 µg/L, in the 2nd
12 trimester (n=317) was 166 µg/L and for women in the 3rd trimester (n=309) it was 156 µg/L
13 (N.S.). Parity was not a significant predictor of UIC. The mUIC of women attending the
14 private practices (n=499) and hospital (n=149) was 179 µg/L and 113 µg/L (p=0.001),
15 respectively.

16 17 *School children*

18 Twenty eight schools participated in the study; the average participation per school was 33
19 children (range 22 to 50). The final sample included 916 children, representing
20 approximately 1 in 700 children in the age group from 6 to 13 years in Switzerland. The mUIC
21 was 120 µg/L (95% CI: 120, 128) and the proportion of children with UIC <100 µg/L was 36%
22 (Table 2). The mUIC of the girls was 113 (95% CI: 105, to 121) µg/L and was significantly
23 lower than the mUIC of the boys, which was 124 (95% CI: 119, 130) µg/L (p<0.0.1). All five of

the geographic regions in Switzerland had a mUIC >100 µg/L with a range from 108 µg/L to 132 µg/L. No significant differences in UIC were found between different ages.

Household salt iodine content

In total, 266 salt samples were analyzed from households of the participating children. Eighty percent (n=213) of samples had iodine concentrations >15 ppm and the median (range) iodine concentration of those samples was 19.8 (15.1-33.0) ppm.

Discussion

Our data indicate iodine sufficiency in the general Swiss population as assessed by indicators recommended by WHO: mUICs in school children and pregnant women are adequate (10). WHO also states a mUIC of ≥100 µg/L indicates iodine sufficiency in infancy (10), and the mUIC in our infants at 3-4 d and at 6 mo was below this cut-off. Infants who were not receiving iodine-fortified IFM during the weaning period were clearly deficient, with a mUIC of 74 µg/L. Several reports of mUIC in infants (<2 y-old) in countries with more-than-adequate or excess iodine intakes have found higher values than in our study (19-22). Studies in European infants have generally reported mUIC similar to ours (19,23-26).

Our findings emphasize the importance of iodine-containing infant foods/formula as dietary iodine sources during weaning. The mBMIC of the mothers in our study was 49 µg/kg, somewhat lower than expected, as a previous Swiss study reported BMICs of ≈60-80 µg/L (23). A review of BMIC among the iodine-sufficient countries reported a wide range of mean or median concentrations, from 50 µg/L in Finland to 270 µg/L in the U.S., but sample sizes

1 were small and not representative, and the potential contribution of iodine supplements
2 was generally not assessed, making it difficult to draw conclusions (36).

3
4 In our infants, only 58% of the 6 mo olds and 18% of the 12 mo olds were being breast-fed,
5 while nearly 2/3rds of all infants were receiving IFM and their UIC was significantly higher
6 than those breast fed (Figure 1). Breast-fed infants who were also receiving IFM had
7 significantly higher UIC than those who were being breast-fed without additional IFM.
8 Infants who were breast fed and given home-prepared complementary foods (CF) (that
9 contain little or no added salt) were at highest risk of low iodine intakes. In Germany, using a
10 dietary model, it was estimated that the iodine intake of an 8 mo-old breast-fed infant who
11 receives home-prepared CF would be only ca. 45 µg/d compared to ≥ 125 µg/d in a formula-
12 fed infant who receives commercial CF (38).

13
14 Previous dietary intake studies have highlighted the importance of iodized CF for weaning
15 infants. In the New Zealand Total Diet study, which simulated typical diets, iodine-containing
16 formula and foods provided 60% of iodine intakes for infants older than 6 mo (39). In the US
17 Total Diet Study, 90% of iodine intake in infants older than 6 mo was provided by infant
18 formula/foods and dairy products (40). In Europe, the required level of iodization for infant
19 formula milks is 10-50 µg/100 kcal (2.5 µg/100 kJ), but for cereal-based and other CFs there
20 are no requirements for minimum iodization while the allowed upper level is 35 µg/100 kcal
21 (7). In the US, iodine fortification of infant formula is mandatory at a minimum level of 5
22 µg/100 kcal (maximum level is 75 µg/100 kcal) (41). In Germany, it is estimated only $\approx 50\%$ of
23 CFs are fortified with iodine (38).

1 The mUIC of pregnant women attending private practices was significantly higher than those
2 attending hospital. This may be due to different dietary habits between these two groups,
3 but it was not explained by increased use of iodized salt in the former group. Although we
4 might have expected mUIC to be higher in the pregnant women who said they were using
5 iodized salt than in those claiming to use noniodized salt, there was no significant difference
6 between the mUIC between these two groups. Because it is estimated that in Western
7 Europe, the majority of salt intake comes from processed foods rather than salt added in the
8 home (42), one possible explanation is that iodized salt intakes from processed foods were
9 similar between groups, as 60-70% of the food industry in Switzerland is using iodized salt
10 (13). Another potential explanation is the relatively small number of women (n=60) who
11 reported using noniodized salt, making the estimate of the mUIC in this group less robust.

12
13 The mothers of the 6 and 12 mo infants were iodine deficient; their overall mUIC was 75
14 $\mu\text{g/L}$ (Table 2), less than half of the median UIC in the pregnant women. Because of iodine
15 secretion into breast milk, the median UIC of the lactating women would be expected to be
16 less than that of pregnant women. However, not all women in the postpartum period were
17 still breastfeeding, and the mUIC of currently breastfeeding women, although lower than
18 that of non-lactating women (67 $\mu\text{g/L}$, n=196 vs. 81 $\mu\text{g/L}$, n=311) was not significantly lower,
19 so losses into breast milk are likely not to be the only explanation for the lower median UIC
20 in the postpartum period. The higher use of iodine containing supplements by pregnant
21 women (15%) compared to women in the postpartum (<5%) may contribute to this
22 difference. It is also possible a proportion of the UI samples collected from pregnant women
23 may have been exposed to iodine contamination from routine clinical use of glucose dip-
24 sticks (43). Glucose dipsticks used in the clinics participating in our study can release large

1 amounts of iodine into urine samples (A.Piacenza, personal communication, 2010). But the
2 most likely explanation for the low mUIC in postpartum women who have finished
3 breastfeeding compared to pregnant women is that their thyroidal iodine stores have been
4 depleted by the very high iodine demands of pregnancy and lactation. Thus, the low mUIC in
5 the post-partum, post-lactation women could reflect greater fractional clearance of
6 circulating iodide by the thyroid in order to rebuild depleted thyroidal iodine stores.

7
8 In our study, supplements containing iodine were consumed by <5% of lactating women.
9 Although iodine supplements (either to lactating mothers or their infants) could supply
10 additional iodine during infancy, most European pediatric societies do not recommend
11 supplements for infants on well-balanced diets or their lactating mothers (44). Similarly, in
12 countries such as Switzerland with an effective iodized salt program, WHO does not
13 recommend iodine supplementation for infants or lactating women (27). Our findings need
14 confirmation in other countries, but suggest these recommendations may need to be
15 reconsidered. In countries where commercial infant foods are available, the fortification of
16 iodine in IFM and CF should be strongly encouraged to ensure adequate iodine intakes in
17 infancy (45).

18 19 **Acknowledgments**

20
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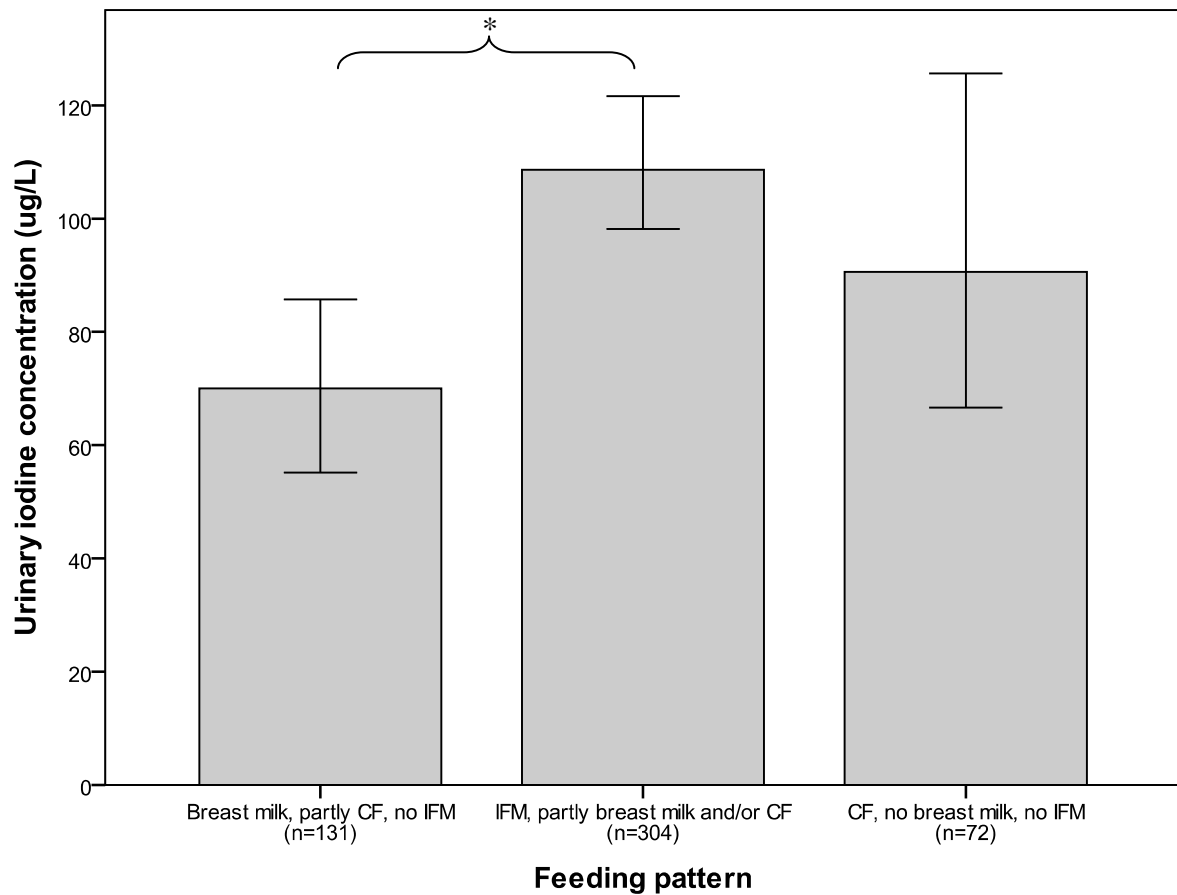


Figure 1: Differences in median urinary iodine concentration (mUIC) between different feeding patterns in 6 and 12 mo old infants. Group 1 (n=131): infants receiving breast milk, partly complementary foods, but no infant formula milk (IFM); Group 2 (n=304): infants receiving infant formula, partly combined with breast milk and/or complementary foods; Group 3 (n=72): infants receiving neither breast milk nor infant formula, but complementary foods. The error bars show the 95% CI. Significant differences between groups: * = $p < 0.01$ (Mann-Whitney U Test followed by Bonferroni correction).

1 **Table 1:** Comparison of labeled and measured iodine concentrations in different brands of
2 formula milk and infant cereals

Brand/ Product specification	Iodine concentration ¹		Measured	Difference
	Labeled [µg/100 kcal] ²	Labeled [µg/100 ml]	[µg/100 ml] ³	[%] ⁴
<i>Infant formulas⁴</i>				
Bimbosan ^a	7.1	4.8	4.6	-3.3
Bimbosan Bio ^a	7.7	5.2	4.5	-13.2
<i>Follow-on formulas⁵</i>				
Adapta 2 ^b	14.5	10	9.1	-8.8
Coop Naturaplan Bio Galactina 2 ^c	14.7	10	12.6	26.5
HiPP Folgemilch 2 ^d	14.3	11	11.6	5.8
Holle Bio 2 ^e	9.3	7	9.4	34.3
Milupa Aptamil 2 ^f	17.6	12	13.2	10.0
Milupa Aptamil HA 2 ^f	19.1	13	11.1	-14.6
Milupa Milumil 2 ^f	19.1	13	11.5	-11.5
Nestlé Beba 2 ^g	23.9	16	14.8	-7.6
Nestlé Beba HA 2 ^g	14.9	10	9.3	-6.9
<i>Soy-based formula</i>				
Bimbosan Bisoja ^a	9.8	6.5	7.8	19.5
Brand/	Labeled	Labeled	Measured	Difference

Product specification	[µg/100 kcal] ⁶	[µg/portion	[µg/portion	[%] ⁴
] ⁷] ⁷	
Instant milk-cereals				
<i>(to be preparation with water)</i>				
Milupa Miluvid plus ^f	19.1	36	33.5	-6.9
Nestlé Baby Cereals Vollkorn mit Früchten ^g	8.5	18	18.3	1.7
Nestlé Baby menu Milchgiess ^g	21.4	45	46.2	2.7
Instant cereals				
<i>(to be prepared with milk & water)</i>				
Galactina				
Ceralino Milchezusatz Getreide & Ovomaltine ^c	10.7	40 ⁷	37.4 ⁸	-6.5

- 1
- 2 ¹ Refers to product as prepared ready-to-eat
- 3 ² Calculated based on energy and iodine per 100 ml ready-to-eat product
- 4 ³ Measured by inductively coupled plasma mass spectrometry (ICP-MS)
- 5 ⁴ Percentage (%) of measured iodine concentrations compared to labeled iodine
- 6 concentration based on µg/100 ml ready-to-drink product
- 7 ⁵ Cow milk-based, HA = partially hydrolyzed milk proteins
- 8 ⁶ Calculated based on energy and iodine per 100 g dry product, except for the Hipp ready-to-
- 9 eat product
- 10 ⁷ Standard portion as indicated on the package, varying from 175 to 200 g

1 ⁸ μg/100g instant powder. Only water used for the preparation
2 ^{a-g}Products of ^aBimbosan Ltd. (Welschenrohr, Switzerland); ^bAdapta (Lenzburg, Switzerland);
3 ^cCoop (Basel, Switzerland); ^dHiPP GmbH (Sachseln, Switzerland); ^eHolle baby food GmbH
4 (Riehen, Switzerland); ^fMILUPA SA (Domdidier, Switzerland); ^gNestlé Suisse S.A. (Vevey,
5 Switzerland).
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7

1 **Table 2:** Urinary iodine concentrations (UIC) by age/population group in Switzerland.

Age group	3-4 d infants	6 mo infants	12 mo infants	Mothers with 6/12 mo infants	School children	Pregnant women
N	368	279	228	507	916	648
Male/female	171/197	142 / 136	106 / 122	All female	464/452	All female
Age (range)		6.2 ± 0.4	12.3 ± 0.4	32.6 ± 4.6	9.6 ± 1.7	31.1 ± 4.9
[Mo, y]		(4.7-7.4) mo	(11.2- 13.4) mo	(15-46) y	(6-13) y	(18-45) y
Weight (kg)	3.4 ± 0.4	7.6 ± 0.9	9.6 ± 1.1	64.9 ± 11.8	35.4 ± 10.2	73.5 ± 30.3
Height/length (m)	Not measured	0.67 ± 0.03	0.75 ± 0.03	1.67 ± 0.06	1.40 ± 0.12	1.66 ± 0.06
UIC (µg/L)						
Median	91	91	103	75	120	162
(95% CI)	(82, 99)	(79, 103)	(92, 116)	(69, 81)	(120, 128)	(144, 177)
Range	4-922	11-759	6-951	6-560	10-408	0-1497
%<20	2 (0.007)	2 (0.008)	3 (0.011)	7 (0.011)	<1	3 (0.007)
% 20-49	20 (0.021)	22 (0.025)	17 (0.025)	23 (0.019)	8 (0.009)	12 (0.013)
% 50-99	36 (0.025)	32 (0.028)	28 (0.030)	34 (0.021)	270.015)	16 (0.014)
%<100	58 (0.026)	55 (0.030)	48 (0.033)	64 (0.021)	36 (0.016)	47 (0.020) ^a
%>300	5 (0.011)	6 (0.014)	4 (0.013)	1 (0.004)	1 (0.003)	25 (0.017)

1

2 ^aPercentage (%) <150 µg/L (10).

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1 **Table 3:** Predictors of urinary iodine concentrations (UIC)¹ in Swiss 6 and 12 mo old infants.

<i>Multivariate regression</i>	<i>β</i>	<i>P</i>
Breast milk iodine concentration (BMIC) ¹	0.320	0.000
Currently consuming infant formula milk (IFM) [yes/no]	0.201	0.010
UIC of mothers ¹	0.107	0.130
Gender infant (f/m)	-0.074	0.291
Currently consuming breast milk [yes/no]	-0.046	0.552
R ² adjusted		0.153

2

3 ¹Values log transformed.